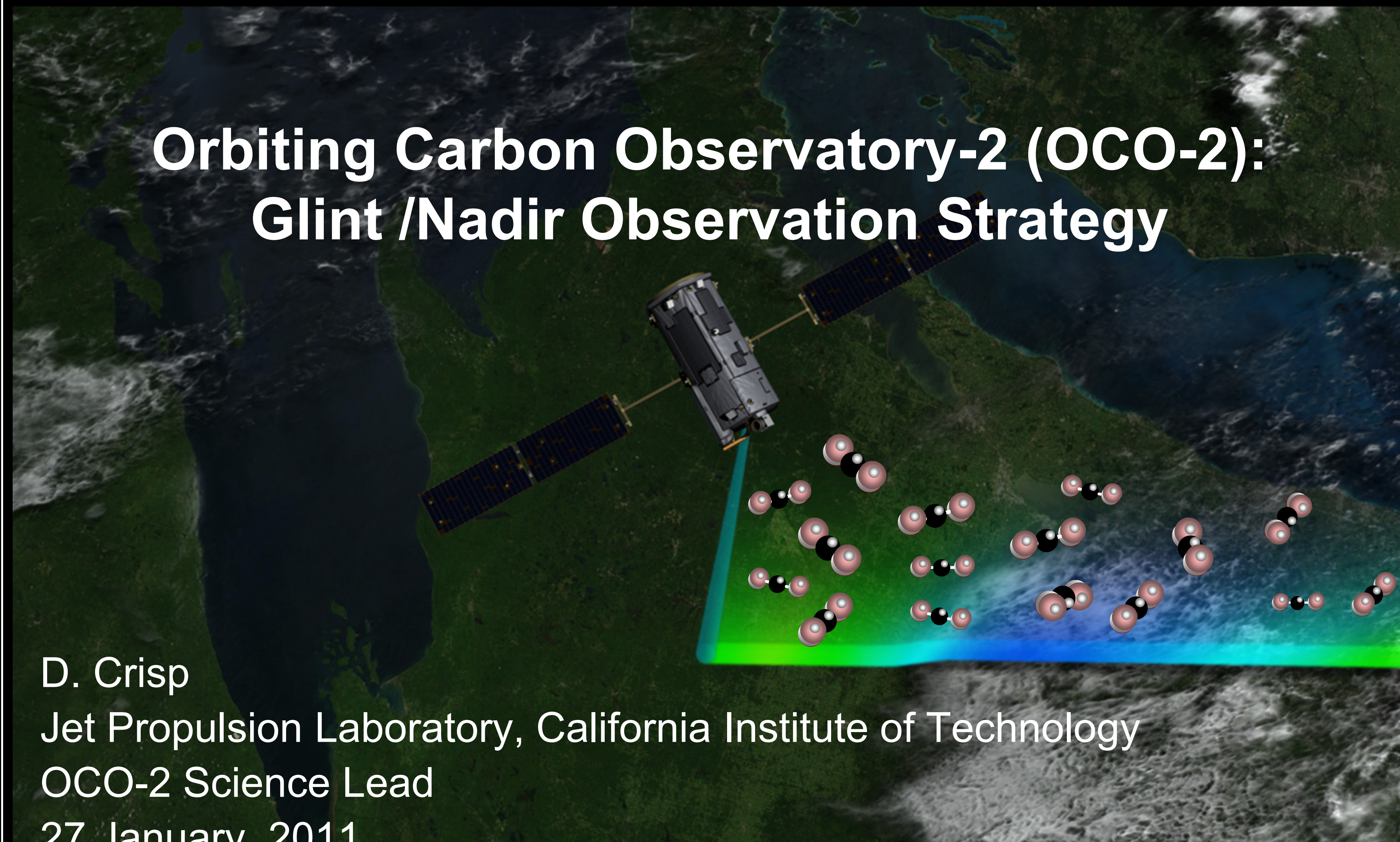
OCO-2 / MicroCarb Meeting, Caltech 27 January 2011



Orbiting Carbon Observatory-2 (OCO-2): Glint /Nadir Observation Strategy

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27 January, 2011

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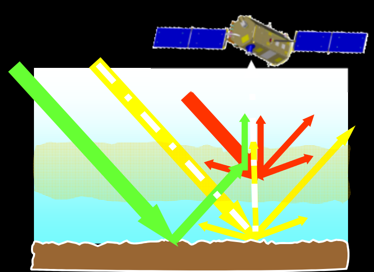
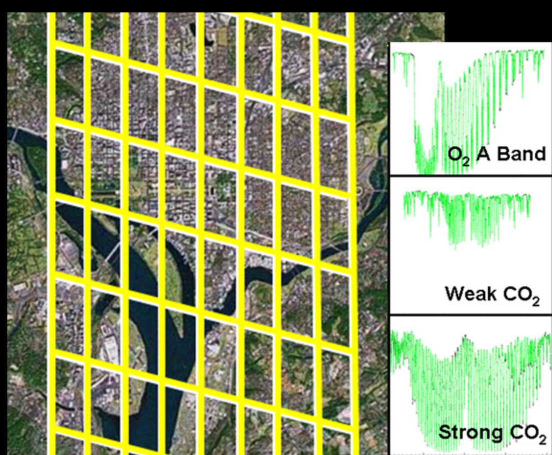
OCO-2 Uses Three Observation Modes

Nadir Observations:

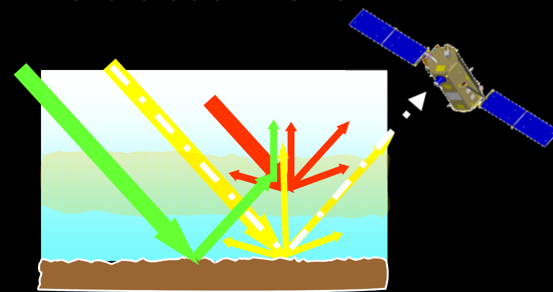
+ Small footprint (< 3 km^2)
– Low Signal/Noise over dark surfaces (ocean, ice)

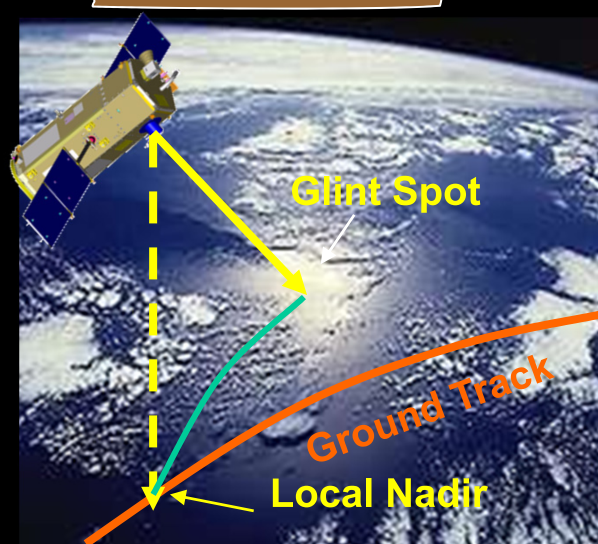




Glint Observations:

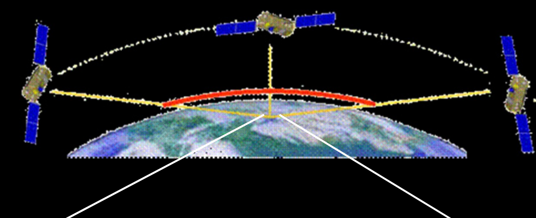
+ Improves Signal/Noise over oceans
– More cloud interference

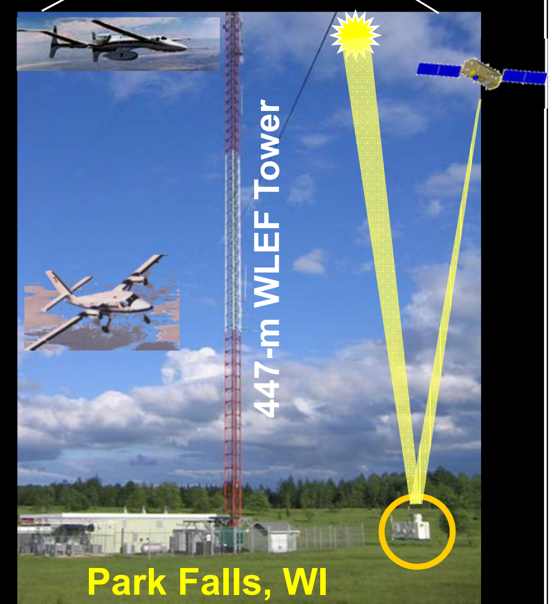




Target Observations:

- Validation over ground based FTS sites, field campaigns, other targets





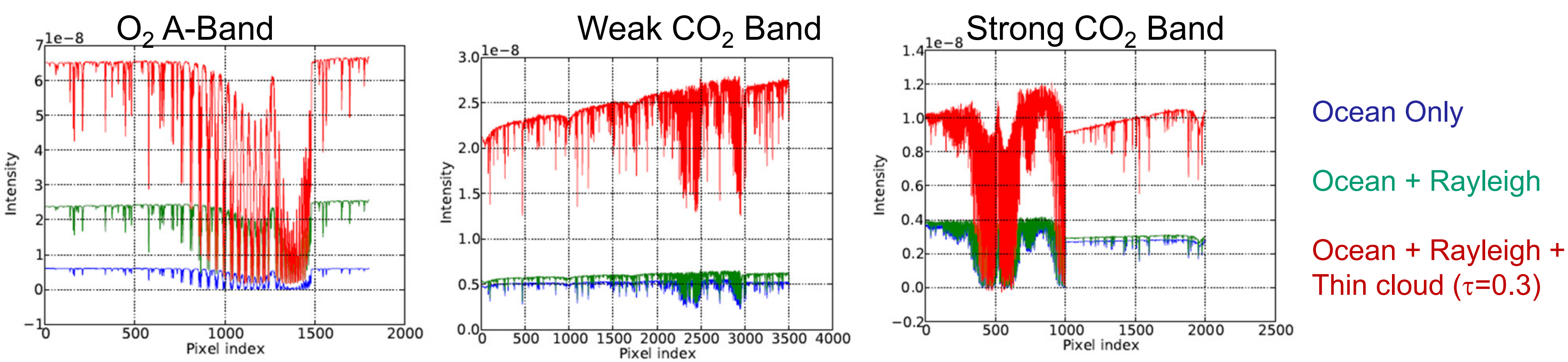
Why are Glint Observations Needed?

- Oceans covers 70% of the surface area of the earth, and are active components of the carbon cycle
  - Each year, the ocean emits ~90 billion tones of carbon into the atmosphere (roughly ten times that emitted by fossil fuel combustion and all other human activities) and absorbs ~92 billion tons of carbon
  - The spatial distribution of this absorption and emission are poorly known
  - Accurate estimates of the CO_2 fluxes between the ocean and the atmosphere are essential for accurate estimates human emissions, especially from coastal sites (where most people live)
- Near IR remote sensing measurements of CO_2 over the ocean are challenging because the ocean reflects very little sunlight
  - Typical nadir reflectances are between 0.5 and 1%
  - Most of the sunlight reflected by the ocean surface is scattered into a narrow range of angles, producing the familiar “glint” spot
  - The reflectivity of the ocean surface increases with the incident solar zenith angle, such that the glint is brightest at high latitudes
  - Waves distribute the reflected sunlight about the specular angle, reducing the peak intensity and increasing the angular size of the glint spot.

Low Surface Reflectance over the Ocean

Typical reflection values over the Pacific Ocean at nadir from the MODIS channels closest to the OCO-2 A-band (band 2), Weak CO_2 (band 6) and Strong CO_2 (band 7) is < 1% (Taylor and O'Brien)

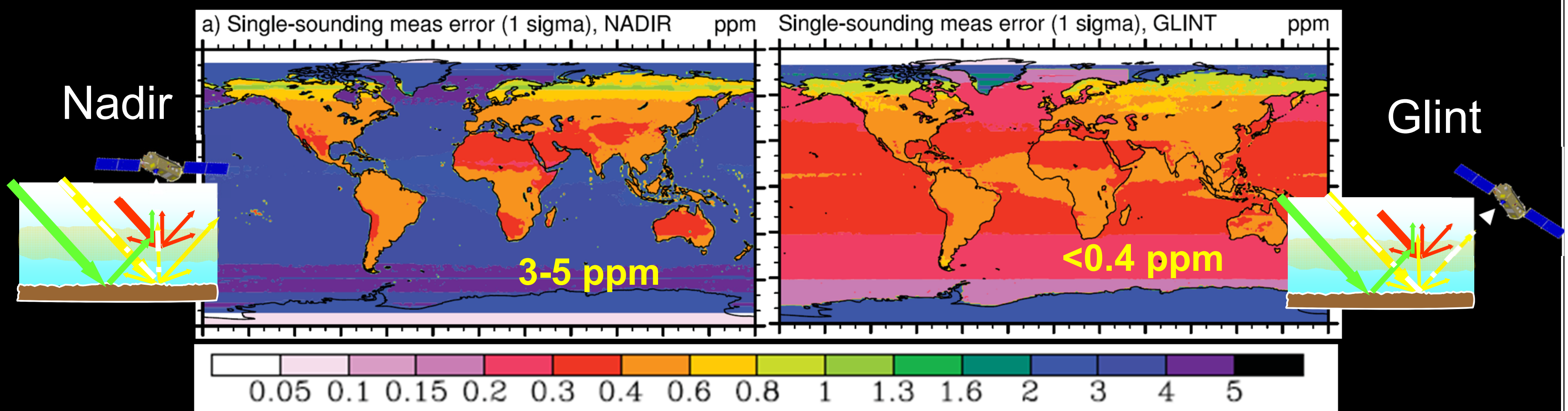
10 km × 10 km region	Band	N	R_{min}	Rmax	Rmean	$\sigma(R)$
	2	98	0.0074	0.0087	0.0079	0.0003
	6	61	0.0011	0.0027	0.0018	0.0002
	7	98	0.0006	0.0015	0.0010	0.0002



- These very low reflection values yield low signal-to-noise ratios
- They also increase pathlength biases from thin clouds and aerosols

OCO-2 Approach: Nadir and Glint Observations

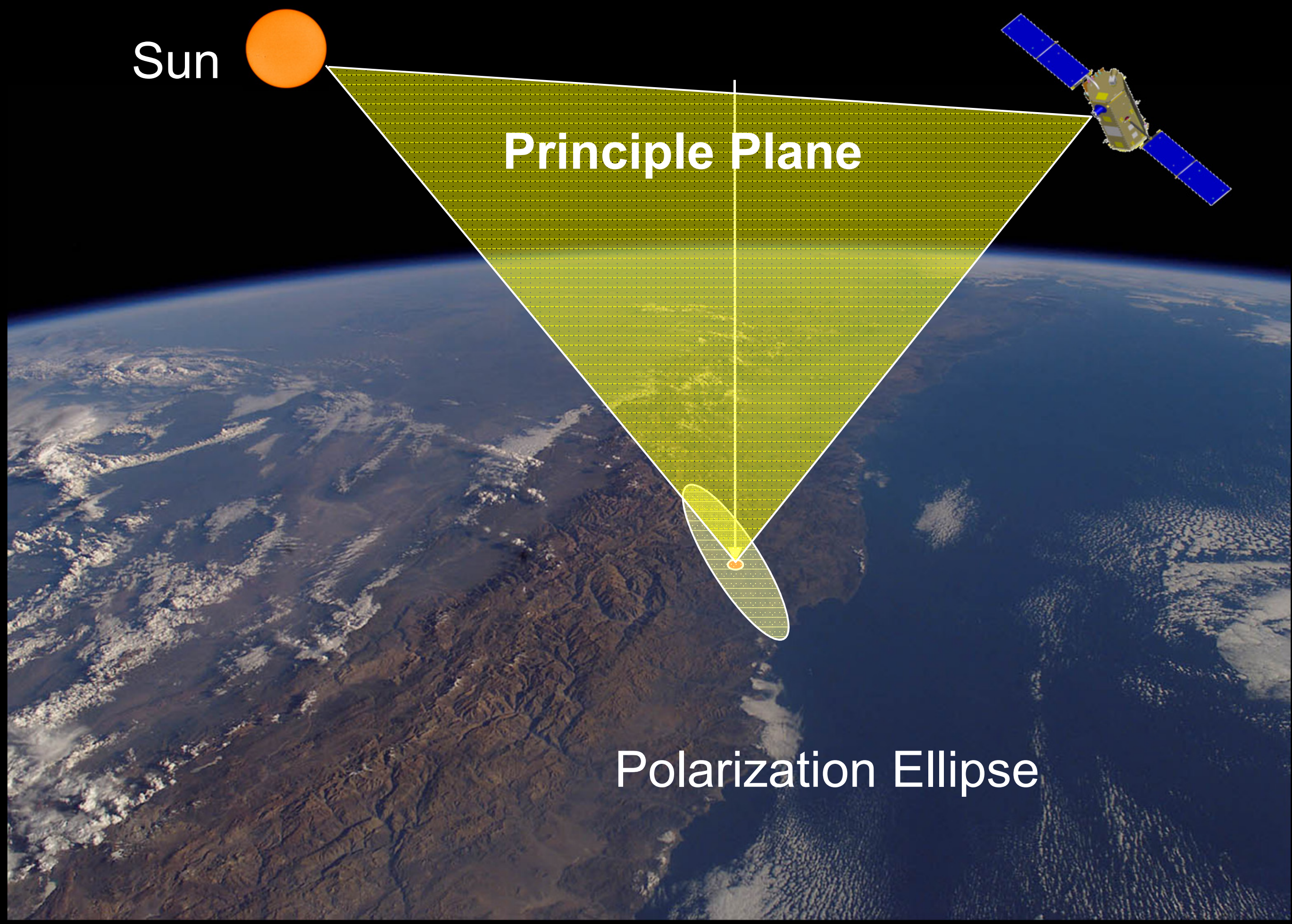
- The OCO-2 mission combines both nadir and glint observations to maximize measurement density over land and SNR over the ocean.
  - Nadir observations yield the highest spatial resolution
    - maximizing the number of cloud-free scenes
    - minimizing pathlength biases from topography
  - Nadir observations provide limited SNR over the ocean
  - Glint observations maximize the SNR over dark, “specular” surfaces, such as ocean and ice covered surfaces, which scatter mostly in the forward direction.



Radiometric and Polarimetric Requirements

- Accurate X_{CO2} retrievals require accurate estimates of the intensity of the incident and reflected sunlight
  - Absolute radiometric errors > 5% or relative (spectral element to spectral element) radiometric errors > 0.1% produce errors in aerosol retrievals that introduce X_{CO2} retrievals error > 0.3% (1 ppm).
- Reflected sunlight can be highly polarized
  - Sunlight polarized in the plane defined by the sun, surface footprint, and instrument aperture (e.g. the "principle plane") can be strongly attenuated, while that polarized perpendicular to this plane is not
- The OCO instrument is sensitive only to the component of the incident radiation that is polarized parallel to the spectrometer slits.
  - Sampling of the polarized radiation field by a polarization-sensitive instrument can introduce radiometric uncertainties that could compromise the accuracy of the X_{CO2} retrievals.
  - Misaligning the instrument's polarization sensitive axis and the peak polarization of the reflected radiation can also substantially reduce SNR over highly polarized scenes, such as the high-latitude ocean

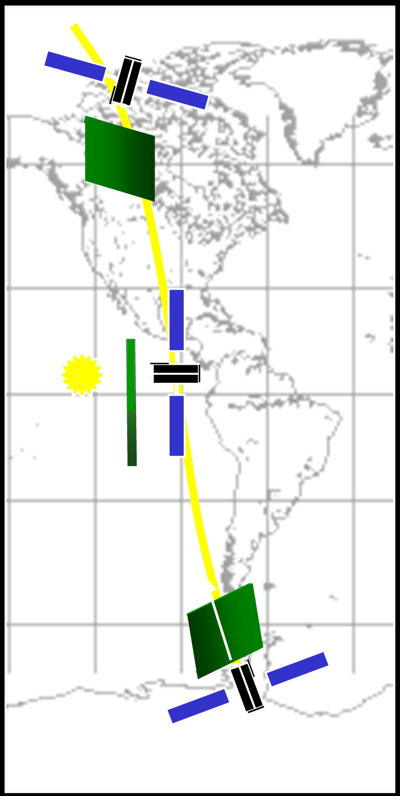
The Principle Plane



The “Principle Plane is defined by the Sun, the surface footprint and the instrument aperture. Sunlight is preferentially polarized perpendicular to the principle plane by Rayleigh scattering and the surface.

Radiometric and Polarimetric Requirements

- If the instrument is sensitive to polarization, some method is needed mitigate the impact of polarization-related radiometric uncertainties and reductions in SNR,
  - the OCO-2 spacecraft orients the instrument such that the instrument's polarization-sensitive axis (parallel to the long axis of the spectrometer slits) remains perpendicular to the principle plane
  - This requires a yaw maneuver (e.g. a rotation about the nadir axis) for both glint and nadir observations
- If a polarization-sensitive instrument is used, and this approach was not practical, another method will be needed mitigate the impact of polarization-related radiometric uncertainties such as
  - Dedicated pointing/rotating mechanism
  - Measure the angle and degree of polarization
  - Scramble the polarization of the incoming signal



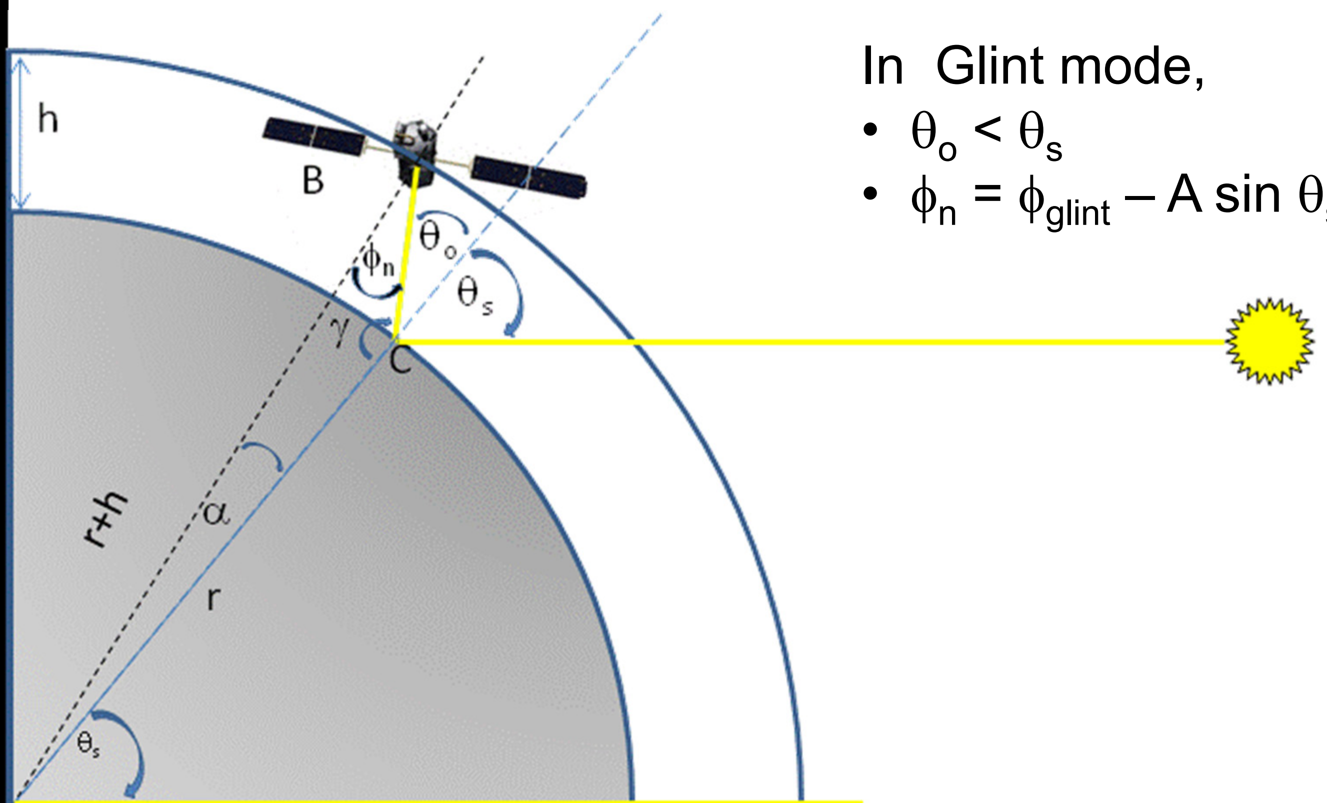
The OCO-2 yaw maneuver maintains spectrometer slits perpendicular to principle plane.

Glint Pointing

- The OCO-2 instrument does not point directly at the glint spot.
- Instead, the instrument bore site is pointed to a footprint along the principle plane between the apparent glint spot and local nadir.
- The spacecraft pointing offset increases with solar zenith angle (SZA),
  - Offset is proportional to $A \times \sin \theta_s$, where θ_s is the SZA at the glint spot
- This prevents the instrument bore site from staring directly at the sun as the observatory approaches the terminator.
- It also expands the range SZA's observable in Glint:
  - If A = 10°, the pointing offset increases from near zero at the sub-solar latitude to 9.6 degrees when $\theta_s = 75°$. There,
    - The instrument bore site is pointing 50.76 degrees away from its local spacecraft nadir (rather than the true glint angle of 60.4 degrees)
    - The bore site is ~81° when the SZA of the apparent glint spot is at 75°.
  - This yields a range of zenith angles for glint observations as +/- 81°
- It also reduces the spacecraft-surface distance and footprint size:
  - The actual distance to the surface is then ~1230 km, such that the footprint size is < 2 times larger than the nadir footprint.

Observation Geometry

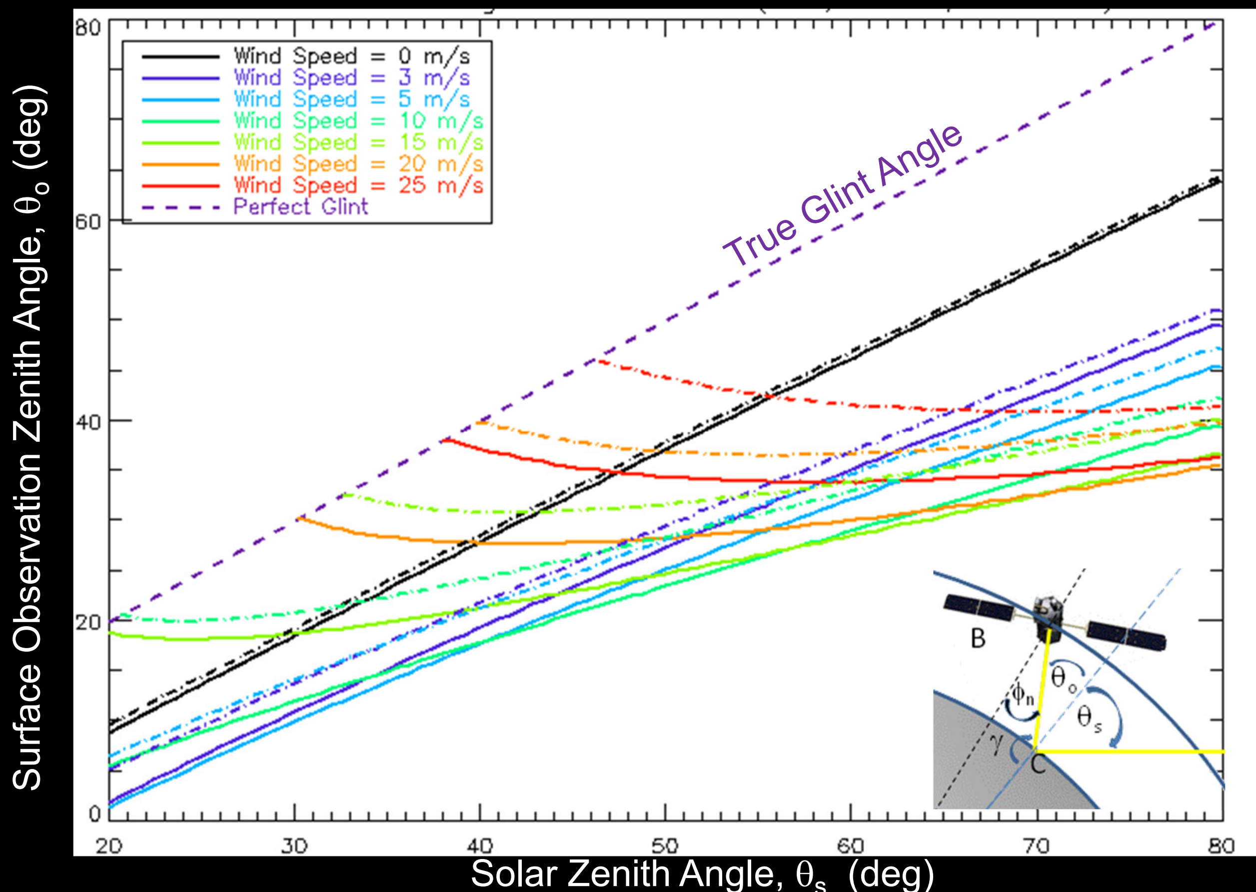
θ_s: Solar zenith angle at surface footprint
θ_o: Observation zenith angle at surface footprint
ϕ_n: Spacecraft nadir observation angle

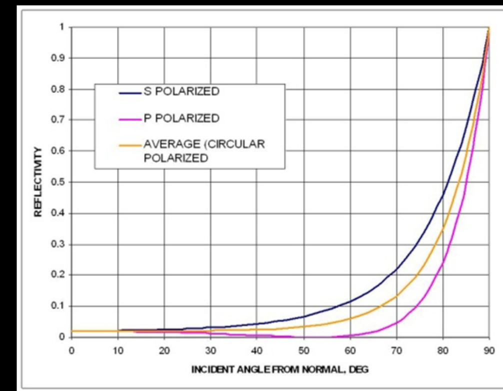


In Glint mode,

- $\theta_o < \theta_s$
- $\phi_n = \phi_{glint} - A \sin \theta_s$

Minimum Nadir Angles Needed for a SNR>200





The reflectivity of a water surface increases rapidly with incident angle (above).

As the solar zenith angle increases, the glint spot becomes brighter and more elongated in the principle plane, such that an observation angle of ~45° is adequate to yield a SNR > 200 for OCO-2.

Minimum observation zenith angle needed to ensure a SNR > 200 is plotted as a function of solar zenith angle and wind speed for the 2.06 micron CO_2 channel (solid lines – low wavelength side of band, dashed lines for long-wavelength side of band).

Conclusions

- Glint measurements are essential to acquire data with adequate signal/noise ratios over dark ocean and ice-covered surfaces

- For OCO-2, the spacecraft bus points the instrument bore site either at the local nadir or at the glint spot for routine science observations
  - In both observation modes, the spacecraft performs a yaw maneuver to orient the instrument slits such that their long axis is perpendicular to the principle plane.
  - The nominal plan is to alternate between glint and nadir observations on alternate 16-day ground repeat cycles, to map out the entire Earth in both glint and nadir modes about once each month.
    - Nadir observations have smaller footprints and are expected to yield more spatially-homogeneous, cloud-free scenes over land.
    - Glint observations are expected to yield higher SNR over dark ocean and ice covered surfaces.
  - Measurements acquired on alternating glint and nadir repeat cycles can be compared to search for systematic biases associated with the observing strategy.